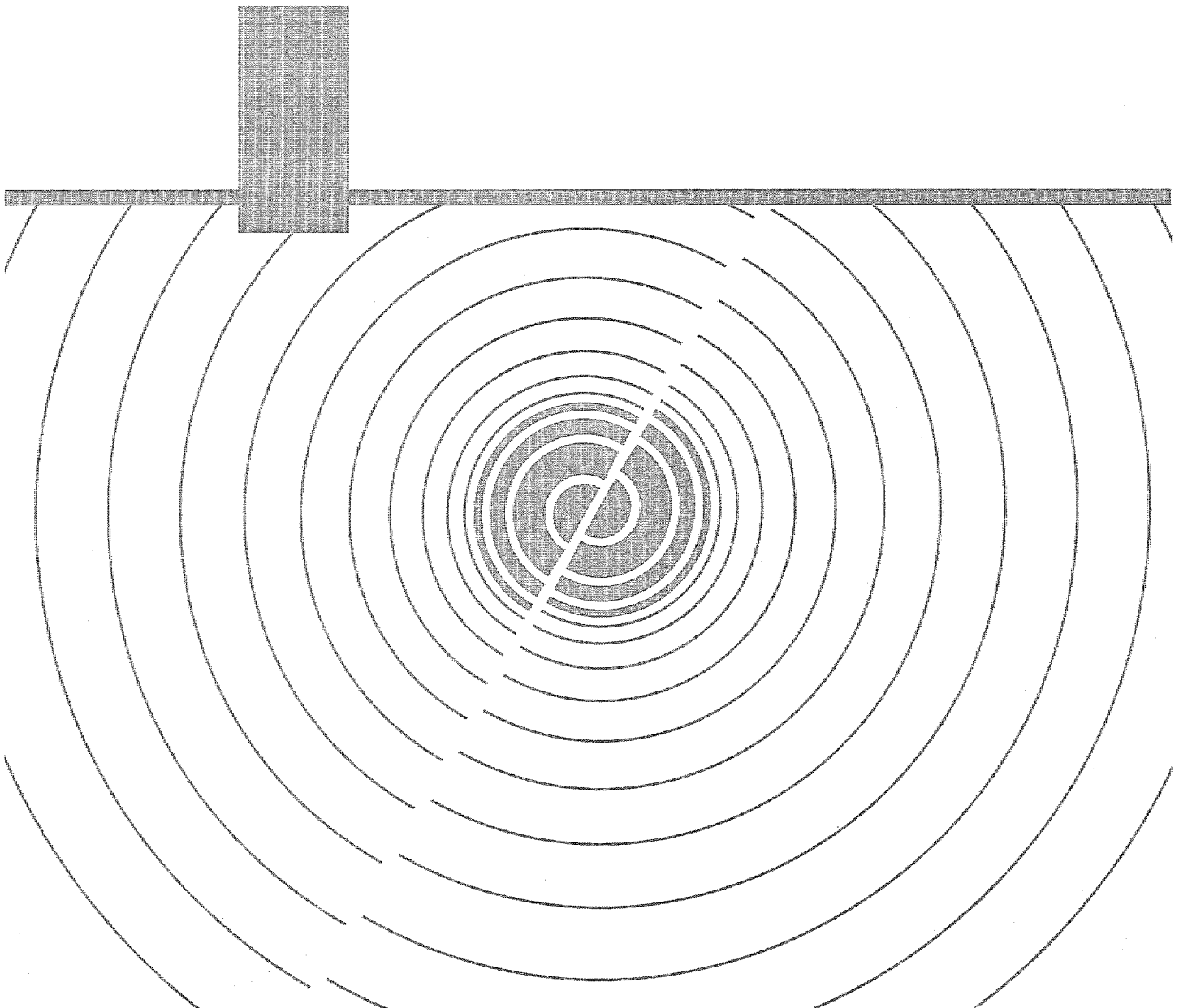

Appendix A:
History and Principles of Seismic Design



Appendix A

History and Principles of Seismic Design



FIGURE A.1 This 8-story reinforced concrete building was one of scores that collapsed during the 1923 Tokyo (Kanto) earthquake. The disaster prompted a limit on building heights. (Source: Carl V. Steinbrugge Collection, Earthquake Engineering Research Center)

History of Seismic Standards

The first quantitative seismic code was developed by an Italian commission following the 1908 Messina-Reggio earthquake, which killed 160,000 people. Following the 1923 earthquake in Kanto, Japan, which killed 140,000 people, the Home Office of Japan adopted a seismic coefficient and a limit on building heights.¹

First U.S. Seismic Codes: UBC and SEAOC in California

The earliest seismic design provisions in the United States were introduced in the appendix to the 1927 Uniform Building Code (UBC), as a result of the 1925 Santa Barbara earthquake.² The 1930 edition included strict specifications for mortar and workmanship on masonry (brick) buildings. However, damage from the Long Beach earthquake of 1933 (Richter magnitude 6.8) proved that unreinforced mortar is unstable in earthquakes. Eighty-six percent of unreinforced masonry buildings in the city of

Long Beach experienced either collapse or extensive damage, rendering the buildings useless. Seventy-five percent of schools were heavily damaged. Soon after this earthquake California enacted the Field Act, which specified seismic design forces for school buildings, and the Riley Act, which mandated seismic design for most public buildings throughout the state.

By the 1950s some California municipalities had adopted additional seismic-resistant design and material specifications. UBC was the first model building code to incorporate comprehensive seismic design requirements, though they remained in the appendix for many years. The 1949 edition of the UBC contained the first national seismic hazard map.

In 1957 the Structural Engineers Association of California (SEAOC) began to develop seismic standards for use throughout the state. SEAOC in 1959 published the first edition of *Recommended Lateral Force Requirements and Commentary*, commonly called the *Blue Book*. The *Blue Book* reflected the latest knowledge of seismic design and was used throughout California. The seismic design provisions remained in an appendix to the UBC until the International Conference of Building Officials (ICBO) adopted the *Blue Book* provisions into the main code in 1961. The seismic requirements of the UBC remained largely unchanged, except for some map revisions, until after the 1971 San Fernando earthquake. Revisions were made to the 1973 UBC, and new requirements, based on the work of SEAOC, were introduced in the 1976 edition.

Federal Involvement Expands: The ATC Project

Early in the 1970s the National Science Foundation (NSF) funded a project, under the guidance of the National Bureau of Standards (NBS, now the National Institute of Standards and Technology), to evaluate existing earthquake-resistant design provisions. In 1974 the NBS contracted the project to the Applied Technology Council (ATC). The ATC is a nonprofit corporation established in 1971 to assist the design practitioner in structural engineering. It is guided by a Board of Directors with representatives from various structural and civil engineering organizations. ATC also identifies and encourages research and develops consensus opinions on structural engineering issues.

Over three years ATC published several drafts, which received extensive peer review. In 1978 ATC published the final report titled *Tentative Provisions for the Development of Seismic Regulations for Buildings* (ATC 3-06). The SEAOC and UBC used the ATC 3-06 report to revise their recommendations and building code.

The NBS in the late 1970s published a *Plan for the Assessment and Implementation of Seismic Design Provisions for Buildings*. This plan analyzed ATC 3-06 and facilitated its development into design standards and building codes.

Further Federal Involvement: NEHRP and the BSSC

In the late 1970s the U.S. Congress passed the Earthquake Hazards Reduction Act of 1977 (PL 95-124), establishing the National Earthquake Hazards Reduction Program (NEHRP), a multi-agency program to fund research and improve practice in reducing earthquake hazards. Since 1977 NEHRP has been the primary source of funding for earthquake research. In 1979 the Federal Emergency Management Agency (FEMA) was established as

the lead federal agency for coordinating NEHRP.

The Building Seismic Safety Council (BSSC) was established in 1979 as an independent voluntary body under the auspices of the National Institute of Building Science (NIBS). The purpose of the BSSC is to provide a national forum to foster seismic safety. The concept of the BSSC was developed by the ATC, SEAOC, NIBS, NSF, National Bureau of Standards (now the National Institute of Science and Technology), FEMA, and American Society of Civil Engineers (ASCE). Currently, members of BSSC come from more than fifty organizations, such as the American Consulting Engineers Council, Masonry Institute of America, and American Iron and Steel Institute, all having interest in seismic-related issues.

Under a contract with FEMA, BSSC revised ATC 3-06 through a consensus process of its members. After balloting BSSC members twice and receiving approval, FEMA released the recommendations in 1985 under the title *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, commonly called the *NEHRP Provisions*. The BSSC, with FEMA funding, continues to update the seismic recommendations using a consensus process. The most current edition was published by FEMA in 1994, and the 1997 edition will be published in early 1998.

Federal Buildings: EO 12699 & EO 12941

The federal government, under presidential Executive Order 12699 (January 5, 1990), now requires seismic design for its new buildings. According to the executive order, titled *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction*, federal agencies must by February 1993 require appropriate seismic design and construction standards for new federal and federally assisted,

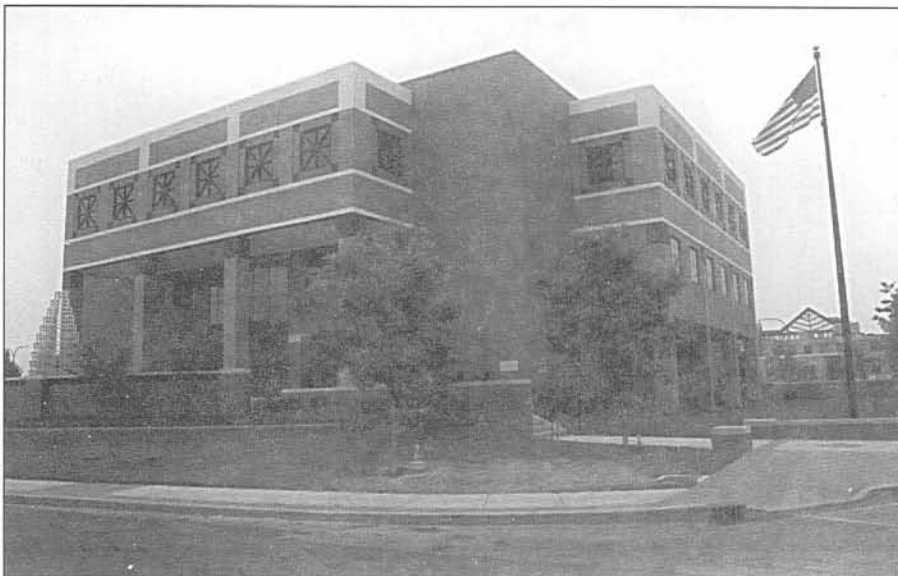


FIGURE A.2 All new federal buildings, such as this federal courthouse in Urbana, Illinois, must be built with seismic design appropriate to the region. (Photo: R. Walker)

leased, and regulated buildings. EO 12699 is significant for state and local governments, because it makes seismic design more prevalent throughout the nation and increases the number of experienced seismic designers and contractors.

Executive Order 12699 is far-reaching, because all new buildings that are owned, leased, or receive federal assistance now must have seismic-resistant design. Also covered are federally regulated or assisted buildings, including single-family homes with Federal Housing Administration or Veterans Administration mortgages.³

Under Executive Order 12699, the seismic design provisions used may be those of the municipality or state in which the building is built, so long as the responsible agency or the Interagency Committee on Seismic Safety in Construction (ICSSC) finds that they provide adequately for seismic safety.⁴ Accordingly, the ICSSC in 1992 recommended the use of standards and practices that are substantially equivalent to the seismic safety levels in the 1988 *NEHRP Provisions*. Each of the following model codes has been found to provide a level of seismic safety substantially equivalent to the 1988 *NEHRP Provisions*: the 1991 *ICBO Uniform Building Code*, the 1992 *Supplement to the*

BOCA National Building Code, and the 1992 *Amendments to the SBCCI Standard Building Code*.

In a May 17, 1995, Recommendation, the Interagency Committee on Seismic Safety and Construction updated this finding. They found that the 1994 UBC, 1993 BNBC, and 1994 SBC provide a level of seismic safety substantially equivalent to that of the 1991 *NEHRP Provisions*. In addition, they found that the National Consensus Standard ASCE 7-93 also provides an acceptable level of seismic safety. Any locality that enforces the current seismic requirements of one of the model codes meets this condition.

The American Society of Civil Engineers' *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-95; see Appendix E for address of ASCE), which supersedes the American National Standards Institute A58.1 standards and subsequent maps adopted for federal use in accord with the order, may be used to determine the seismic hazards in various parts of the country. ASCE 7-95 includes specifications for calculating forces that the building must support, such as earthquake, wind, snow, and building material forces.

Because of EO 12699, it is in the best interests of local governments to adopt seismic codes. To best facilitate the possibility of federal financial assistance for new buildings, local governments would be well advised to adopt one of the model codes that have been found to be seismically adequate. For example, the federal agencies providing financial assistance for housing construction (VA, FHA, HUD) all now require adequate seismic design and construction.

EO 12941, by adopting the *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings*, by the Interagency Committee on Seismic Safety and Construction (ICSSC), promulgates a set of seismic standards for federally

owned or leased buildings. It also establishes five triggers for evaluation and possible mitigation of risks in a building. For example, when there is a change of building function, a building is significantly altered, or it has to be rebuilt following a disaster, the building must be evaluated according to the ICSSC standards.⁵

Federal Agency Practices Prior to EO 12699: Some Examples

Prior to EO 12699, many agencies of the federal government had promulgated their own building regulations for federally owned and funded projects. Because of the influence of the federal agencies' standards, increasing numbers of structures throughout the United States have been built to seismic-resistant standards.

The recognized authorities for highway bridge earthquake-resistant design are the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA). AASHTO has published *The Standard Specifications for Highway Bridges* since 1931 (see Appendix E for address of AASHTO). AASHTO's expressed purpose for publishing these specifications is to guide the preparation of state specifications. The latest edition was published in 1995, and supplements are released yearly. Although seismic design standards were not incorporated into AASHTO's specifications until 1991, they had been adopted as guidelines since 1983. States must use AASHTO specifications in order to receive federal highway funds.

The federal government, through the Interagency Committee on Dam Safety, has published *Federal Guidelines for Earthquake Analysis and Design of Dams*. These guidelines were created to develop consistency among federal agencies involved in the planning, design, construction,



operation, maintenance, and regulation of dams.

The 1971 San Fernando, California, earthquake caused a Veterans Administration hospital to collapse. Since then the VA has required its facilities to be designed with earthquake-resistant provisions, in accordance with a seismic design manual published by the VA Office of Facilities.

Principles of Seismic Design⁶

The Goals of Seismic Design

Seismic design provisions are intended to protect the safety of a building's occupants during and immediately following an earthquake. Building codes are primarily designed to save lives and reduce injuries, not to eliminate property loss. Their purpose is to allow for safe evacuation of a building. Seismic provisions attempt to prevent general failures (total collapse), but allow for local damage (damage to noncritical sections). Therefore, a building in compliance with the code probably will not collapse, but it may be rendered unfit for continued use. According to the Structural Engineers Association of California, structures built

FIGURE A.3 Following the collapse of the Veteran's Administration hospital in the San Fernando earthquake of 1971, the VA has required seismic design for all its facilities. The hospital building shown in this photo was constructed in 1925 with concrete frames and concrete floors, and hollow-tile walls. This type of building is known to be hazardous in the event of a strong earthquake. (Source: Engineering Features of the San Fernando Earthquake, California Institute of Technology, EERL, 1971)

according to a seismic code should resist minor earthquakes undamaged, resist moderate earthquakes without significant structural damage even though incurring nonstructural damage, and resist severe earthquakes without collapse. Building codes are only minimum design standards.

Lateral Earthquake Forces

Today's seismic provisions specify how to calculate the unique earthquake-induced *lateral force*. These are horizontal forces generated by the ground's side-to-side movement in an earthquake.

The purpose of earthquake engineering and earthquake-resistant design is to construct buildings that can resist horizontal forces. This notion is central to seismic building design. All buildings are designed to stand under the vertical forces of gravity, an obvious constraint because it is always present. Less apparent is the need to design for the occasional occurrence of horizontal forces. Many cities have learned the hard way, after it is too late, that their brick or adobe buildings (or concrete and steel buildings not seismically designed) cannot withstand earthquake ground-shaking.

In designing a building, a structural engineer combines the earthquake-induced lateral force with other code-specified forces, such as wind or snow load, to obtain the maximum probable force. The structure is designed based on the maximum combination. The calculated earthquake forces may be less than the wind or snow force.

Buildings that are tall or have unusual shapes require more extensive design analysis. When a building has a complex shape the designer must employ a dynamic structural response analysis, a computer analysis that simulates the building's swaying (side-to-side movement) during an earthquake.

The model reflects the building's behavior, conceptually similar to a vibrating string. The dynamic analysis is more accurate than the simple or "static" analysis but is more time-consuming and costly; therefore it is only used for large-scale structures in which many people could be hurt.

The Council of American Building Officials (CABO) has incorporated construction specifications that increase earthquake resistance for one- and two-family dwellings. The *CABO One- and Two-Family Dwelling Code* contains specific requirements for reinforcing chimneys and fireplaces, tying the building frame to the foundation, and providing walls more resistant to earthquake motion (shear walls). These provisions help to prevent chimneys from falling and homes from shifting off their foundation.

Ductility

Another aspect of seismic design is called *ductility*, the flexibility of buildings. In simple terms, buildings are designed to bend rather than break under earthquake forces. Ductility is the ability of a material to deform without fracturing. For example, ductility is an inherent property of steel. Steel will bend significantly before it ultimately fails, which is called ductile failure. Designing an entire structure to be ductile allows for the parts of a building to deflect in an earthquake before they fail.

In contrast to ductile failure, *brittle failure* occurs without prior visual indication. Unreinforced masonry and unreinforced concrete structures are inherently brittle materials. Steel reinforcement transforms concrete's behavior from brittle to ductile. The American Concrete Institute (ACI) through its *Building Code Requirements for Reinforced Concrete* (ACI 318-89) provides specific criteria for structural design of reinforced concrete structures. One provision is the

specification of a minimum amount of reinforcing steel to provide for ductile behavior.

Drift

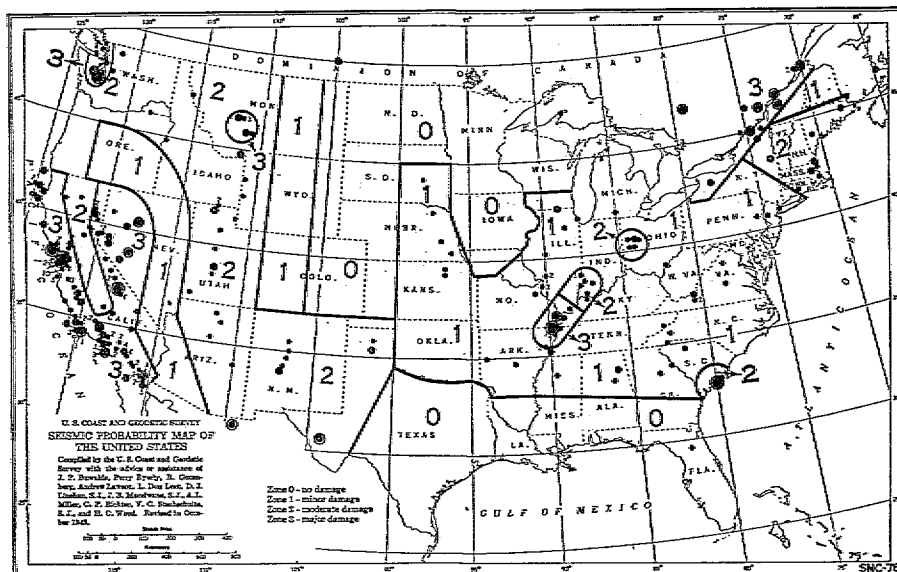
The codes also try to limit the sway of buildings. This is to prevent nonstructural damage and equipment and inventory damage. Although the structural frame can resist stresses and strains created by *drift*, or horizontal movement of one floor relative to the other, items that are attached to the frame or within its interior may not. The John Hancock Building in Boston in the 1970s had problems caused by excessive drift. Windows crashed to the ground as the building swayed in the wind, until the building was retrofitted to reduce the amount of sway. Damage occurred in Mexico City's 1985 earthquake when swaying buildings pounded into each other. Pounding was a significant factor in 40 percent of the collapsed buildings.⁷ The drift was due to inadequate stiffness in building frames and the small distances separating buildings.

Seismic Hazard Maps

All the model codes include a seismic hazard map that indicates likely levels of earthquake ground-shaking and, therefore, potential structural damage in every part of the United States. The hazard map is based on the probability that a specified earthquake intensity will occur during a defined time period.

First Seismic Hazard Map Was Based on Maximum Historic Earthquakes⁸

The first seismic hazard map was published in 1948 by the U.S. Coast and Geodetic Survey and was adopted in the 1949 edition of the UBC, as well as subsequent editions until 1970. In 1969 S.T. Algermissen of the U.S. Geological Survey (USGS) published a seismic hazard map for the contiguous forty-eight



states. The original map was created by plotting historical earthquake occurrences and was based only on the recorded maximum earthquake intensities. Because of this, portions of the northeast United States were assigned the same hazard and design requirements as areas in California. This map was the basis for the zoning map in the 1970 UBC, which divided the United States into four zones numbered 0 through 3. A zone 4 was added to California in the 1976 UBC.

FIGURE A.4 The 1948 seismic hazard map. (Source: U.S. Coast and Geodetic Survey)

1976 Map: Probabilities of Ground-Shaking

In 1976 Algermissen and coworkers refined the map to incorporate the probable frequency of various earthquake intensities. Thus, areas with more frequent earthquakes would be subject to stricter standards of design. They mapped the peak ground acceleration, a measure of the maximum force of earthquake ground-shaking, according to different earthquake intensities expected across the United States. The 1976 map by Algermissen and others depicts the peak ground acceleration that has a 10 percent probability of being exceeded every fifty years. The fifty-year period is typically used as a structure's design lifespan, and 10 percent is consid-

Table A-1 State Codes and Code Influence

| State | State Code Name | Basis* | Edition |
|-------------------|--|--------|---------|
| Alabama | Alabama State Code | SBC | 1994 |
| Alaska | Alaska State Code | UBC | 1994 |
| Arizona | None | | |
| Arkansas | Arkansas Fire Prevention Code | SBC | 1991 |
| California | California Building Code | UBC | 1994 |
| Colorado | UBC | UBC | 1991 |
| Connecticut | Connecticut State Building Code | BNBC | 1992 |
| Delaware | None (done at county level) | | |
| Dist. of Columbia | DC Building Code Supplement | BNBC | 1990 |
| Florida | SBC, EPCOT, So. Florida Bldg. Code | | 1994 |
| Georgia | Georgia State Minimum Std. Bldg. Code | SBC | 1994 |
| Hawaii | None (done at county level) | | |
| Idaho | UBC | UBC | 1994 |
| Illinois | State (plumbing only) | State | 1993 |
| Indiana | Indiana Building Code | UBC | 1991 |
| Iowa | Iowa State Building Code | UBC | 1991 |
| Kansas | None (uses UBC) | UBC | 1991 |
| Kentucky | Kentucky Building Code | BNBC | 1993 |
| Louisiana | State Uniform Construction Code | SBC | 1991 |
| Maine | None | | |
| Maryland | Model Performance Code | BNBC | 1993 |
| Massachusetts | Massachusetts State Building Code | BNBC | 1987 |
| Michigan | Building Code Rules | BNBC | 1993 |
| Minnesota | Minnesota State Building Code | UBC | 1994 |
| Mississippi | None | | |
| Missouri | None | | |
| Montana | Admin. Rules of Montana, Ch. 70 | UBC | 1994 |
| Nebraska | State Fire Marshall Act | UBC | 1979 |
| Nevada | Nevada State Fire Marshall Regulation | UBC | 1991 |
| New Hampshire | State Statute | BNBC | 1990 |
| New Jersey | State Uniform Construction Code | BNBC | 1993 |
| New Mexico | New Mexico Building Code | UBC | 1991 |
| New York | Uniform Fire Prevention & Bldg. Code | State | 1995 |
| North Carolina | State Building Code | SBC | 1994 |
| North Dakota | Century Code | UBC | 1994 |
| Ohio | Ohio Basic Building Code | BNBC | 1993 |
| Oklahoma | Title 61, Oklahoma Statutes | BNBC | 1993 |
| Oregon | Oregon Structural Specialty Code | UBC | 1991 |
| Pennsylvania | None | | |
| Rhode Island | State Building Code | BNBC | 1990 |
| South Carolina | SBC | SBC | 1991 |
| South Dakota | Fire Safety Standards | UBC | 1991 |
| Tennessee | SBC | SBC | 1994 |
| Texas | None | | |
| Utah | Utah Uniform Building Standards Act | UBC | 1994 |
| Vermont | Vermont Fire Prevention & Bldg. Code | BNBC | 1987 |
| Virginia | Virginia Uniform Statewide Bldg. Code | BNBC | 1993 |
| Washington | State Building Code | UBC | 1994 |
| West Virginia | State Building Code | BNBC | 1990 |
| Wisconsin | Bldg., Heating, Ventilation & A/C Code | State | |
| Wyoming | State Code, Ch. 9, Fire Prevention | UBC | 1994 |
| Guam | UBC | UBC | |
| Puerto Rico | Puerto Rico Building Code | | |
| Virgin Islands | UBC | UBC | 1994 |

*Model code on which state code is based.

Sources: Insurance Institute for Property Loss Reduction (now IBHS), April 1996; information on territories was collected by the authors from FEMA and NCSBCS.

ered to be a large enough probability to warrant concern.

It is important to appreciate the probabilistic nature of the Algermissen map. We cannot justify the expense of designing for large but highly improbable events. So we select an event (called the *design event*) that, although large and rare, has a reasonable chance (10 percent) of being exceeded during a building's lifetime (fifty years). The probability selected reflects society's attitude toward risk. This risk acceptance may vary for different uses. Nuclear power plants, for example, are built to much more stringent seismic standards.

It is also important to realize that there is always a chance that an event will exceed the design event—indeed, there is a 10 percent chance of an earthquake that exceeds the design standard. Seismic design standards represent society's balancing of the risks and the costs of designing to withstand that risk.

Finally, one must realize that the zone boundaries themselves are based on probability. There is nothing sacred about the lines on the map; a structure on one side of a zone line is not markedly safer than a structure immediately on the other side. But these maps do represent a consensus of informed scientific opinion of the likelihood of earthquake ground-shaking and its effects. By using these maps as guides to design, we reduce the overall chances of damage to buildings in a region.

ATC Adaptation of the Probabilistic 1976 Map

The ATC revised the 1976 Algermissen map by converting the peak ground acceleration values to effective peak acceleration (EPA) values, another way of describing earthquake ground-shaking. There is no single perfect measure. How-

ever, in making the map more user-friendly, it lost accuracy. The effective peak acceleration maps depict peak ground acceleration that has a 5 to 20 percent probability of occurring in a fifty-year period.

From effective peak acceleration, ATC also developed an effective peak velocity map. Effective peak velocity measures the sustained ground movement during an earthquake and is more suitable for building code application to taller buildings. In addition, the ATC maps were revised to follow the boundaries of political jurisdictions to clarify the zones for local building code administration. These maps in ATC 3-06 were used as the basis for the zone map in the *NEHRP Provisions*. A more refined map by the U.S. Geologic Survey appeared in the 1988 *NEHRP Provisions* and has since been adopted by BOCA and SBCCI. The current UBC model building uses similar information for its seismic zone map. The map divides the United States into six earthquake risk zones: 0, 1, 2a, 2b, 3, and 4.

Current Efforts by USGS

The U.S. Geological Survey has recently developed a new generation of seismic hazard maps. These maps are based on the more complete spectrum of ground response to seismic waves, rather than the traditional acceleration and velocity maps. They also use shaking exceedance probabilities of 2 percent and 5 percent in 50 years, in addition to the probability of 10 percent in 50 years that has traditionally formed the basis of seismic hazard maps.⁹ The maps currently being balloted for inclusion in the *NEHRP Provisions* are based on the 2 percent in 50 year USGS map, with some changes in high-seismic near-fault areas. The maps will be published with the 1997 edition of the *NEHRP Provisions* and will ultimately be used in the 2000 International Building Code.

NOTES

- 1 Building Seismic Safety Council, *Improving the Seismic Safety of New Buildings: A Community Handbook of Societal Implications*, FEMA #83, July 1986 edition.
- 2 This history of seismic codes comes from a number of sources, most notably: Beavers, James E., "Perspectives on Seismic Risk Maps and the Building Code Process," in *A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987*, Walter Hays, ed., U.S. Geological Survey Open-File Report 88-13-A, 1988, 407-432; Whitman, R.V., and Algermissen, S.T., "Seismic Zonation in Eastern United States," *Proceedings, Fourth International Conference on Seismic Zonation*, Vol. I, Earthquake Engineering Research Institute, 1991, 845-869; Martin, H.W., "Recent Changes to Seismic Codes and Standards: Are They Coordinated or Random Events?" *Proceedings, 1993 National Earthquake Conference*, Vol. II, Central U.S. Earthquake Consortium, 1993, 367-376.
- 3 National Institute of Standards and Technology, *Guidelines and Procedures for Implementation of the Executive Order on Seismic Safety of New Building Construction*, ICSSC RP2.1A, NISTIR 4852, June 1992.
- 4 Ibid.
- 5 Todd, Diana, ed., *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings*, National Institute of Standards and Technology Report NISTIR 5382, Interagency Committee of Seismic Safety and Construction Recommended Practice 4 (ICSSC RP 4), February 1994.
- 6 This summary of seismic design comes from a number of sources, most notably from the Building Seismic Safety Council: *Improving the Seismic Safety of New Buildings: A Community Handbook of Societal Implications*, FEMA #83, July 1986 edition; *Seismic Considerations for Communities at Risk*, FEMA #83, September 1995 edition; and *Nontechnical Explanation of the NEHRP Recommended Provisions*, FEMA #99, September 1995. Also see EERI Ad Hoc Committee on Seismic Performance, *Expected Seismic Performance of Buildings*, Earthquake Engineering Research Institute, February 1994; and Lagorio, Henry J., *Earthquakes, An Architect's Guide to Nonstructural Seismic Hazards*, John Wiley and Sons, Inc., 1990.
- 7 Geis, Donald A., et al., "Architectural and Urban Design Lessons from the 1985 Mexico City Earthquake," *Lessons Learned from the 1985 Mexico Earthquake*, Earthquake Engineering Research Institute, 1989, 226-230.
- 8 The information on seismic hazard maps comes from a number of sources, most notably: Beavers, James E., "Perspectives on Seismic Risk Maps and the Building Code Process," in *A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987*, Walter Hays, ed., U.S. Geological Survey Open-File Report 88-13-A, 1988, 407-432; Whitman, R.V., and Algermissen, S.T., "Seismic Zonation in Eastern United States," *Proceedings, Fourth International Conference on Seismic Zonation*, Vol. I, Earthquake Engineering Research Institute, 1991, 845-869; U.S. Department of the Interior, Geological Survey, *USGS Spectral Response Maps and Their Relationship with Seismic Design Forces in Building Codes*, Open-File Report 95-595, 1995; and Leyendecker, Edgar V., Algermissen, S.T., and Frankel, Arthur, *Use of Spectral Response Maps and Uniform Hazard Response Spectra in Building Codes*, Fifth National Conference on Earthquake Engineering, July 1994.
- 9 Leyendecker, E.V., et al., *USGS Spectral Response Maps and Their Relationship with Seismic Design Forces in Building Codes*, U.S. Geological Survey Open-File Report 95-596, 1995. The most recent versions are available at <http://gldage.cr.usgs.gov/eg/>